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Parametric Performance of Condensation Factors for Extracting Potable Water from Atmosphere

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Abstract: Alternative recent technologies are sought-after to resolve the hastily growing water scarcity globally. The innovative techniques contributing to the water production implementing the method of condensation provides feasible study specifying factors affecting. The factors investigated from extant literature are reviewed to perform weightage to the criteria and ranking to the recognized condensation phenomenon. The weightage of the criteria is characterized by the implementation of the ENTROPY approach and the ranking of factors is performed by the MOORA method. The purpose of this manuscript is to strengthen different factors of sustainable water harvesting using condensation methods for efficiency improvements. The harvesting application with modified factors to their required hierarchy certainly proposes an economic and scalable to emerging and existing potable water generating system. The precise configuration of condensation factors will introduce environment-friendly, effective, and sustainable water-extracting systems in various fields.

Keywords: condensation; factors; potable water; ENTROPY approach; MOORA method

1. Introduction

The expanding water scarcity became a spatial resolution to every part of the world specifically in arid and drought-prone region[1]. Solutions for potable water dependent on various strategies such as recycling of used water, water-saving planning, and water harvesting[2]. However, recycling of used water may be affected by micro-organisms which need different methodologies for purification hence extends expense. Rainwater harvesting methods can be opted for water-saving planning but suffer from chronic severe and concludes as seasonal and completely climatic[3]. Thus, the water production from the atmosphere's thin air, fog, and clouds are considered an enormous and renewable resource of water approximately 12.9 trillion tons of fresh water[4-7]. Thereby, production of water from atmosphere can be considered as another source of potable water [8,9]. The production and collection of atmospheric moist air by phase change can be performed by fabrication of diverse and sustainable harvesting apparatuses and techniques in every region[10].

It has been reported by many authors that the condensation phenomenon using appropriate environmental conditions and techniques serves to a large-scale generation of water[11-13]. The condensation process involves mass and heat transfer which have two paradigms in proceeding as dropwise or film-wise. Besides, the dropwise condensation is performed more to attain a higher order rate of heat transfer offers low wetting than the condensation of film-wise[14]. In this method, the moist air changes the phase due to a change in temperature lower to dew point on cooling surfaces. To achieve effective and efficient phenomenon of dropwise condensation in phase-change heat transfer, a process is required to perform under controlled environment condition[15]. When the factors responsible are properly coordinated and matched the controlled conditions, help to achieve, and enhance the condensation process. Accordingly, the preferred embodiment condensation device appends the claim of effective and efficient accumulation of water. The directional design and fabrication of factors act together to reach continuous and massive rate condensation. The structural layout of independent and dependent factors features and exhibits its potential and capacity[16]. The challenging and harsh conditions of industry insight to assesses the mechanism and sustainable fabrication indeed accurate phase transfer[17]. The ability to enhance condensation with the associated mechanism of factors is nowadays a demand in the field of engineering, medical, industry, and research. The imprudent usage of the devices associated with the condensation process pollutes concisely the environment which can be strengthened by prioritizing them in ranked order of their best performance. This practice not only provides fundamental insights but also exposes an avenue to countercheck the suitability of associated devices to their correct location.

The manuscript is originated to investigate the ranking of the investigated factors that entirely affecting the phenomenon of condensation. The investigated factors are considered as influential factors which means the factors that can apply a visible effect on the condensation process in a positive or negative way. Thereby, the assessment of factors is performed to understand the complete fundamental importance of ranking. The execution of comparative assessment is achieved by implementing the ENTROPY approach and MOORA method. The complexity and parameter dependencies under suitable environmental conditions of condensation step up to configured and managed condensation process due to knowing the weightage and ranking of impacting factors. Thus, the influential factors dependent on environmental conditions are procured conserving environmental pollution also.

The constructive alignment of this manuscript is sketched in coming sections as follows: section 2 elaborates about the condensation key factors sought from the literature review. The factors are analyzed for their functional performances in the phenomenon of condensation for water harvesting. Section 3 includes the methodology implementation to complete the research procedure and further concluded with the results also. Section 4 summarizes about findings of the parametric evaluation of the condensation factors.

2. Factors affecting condensation

The factors which contributed to an assessment of the significant performance of condensation are shown in Fig. 1. The literature review defined the numerous factors which can impact the condensation process, but after the long discussion and brainstorming with industrialist, academicians, and researchers we identified the six influential factors which are needed to study further. The six influential factors are as follows:

2.1 Condensing Surface (F_1)

The surfaces expended to the production of condensed water are termed condensing surfaces. The phenomenon of condensation practically exhibits on this surface including all variations. Modified condensing surfaces support and significantly enhances the efficacy of thermal transport. The moist air condensation proceeds by the nucleation of distinctive drops on a condensing surface. Thus, the condensing surfaces contribute to the high productivity of water flux at the rate of thermal efficiency. Therefore, it acts as one of the urge factors in completing the phenomenon of condensation[18,19].

2.2 Surface Coating (F_2)

On condensing surface, condensate must be promptly drifted to accumulate otherwise a poor thermal conductivity of liquid transport will be induced. Thus, to approach rapid removal of drops, the surfaces are preferred to coating[13]. The surface coating provides a spontaneous motion that is driven by the surface energy allows for easier slide-off of condensate droplets. Therefore, it is found that surface coating is an important factor that precisely influences droplet growth and self-propelled motion in the process[20,21].

2.3 Relative Humidity (F_3)

Among the several important factors, relative humidity is one of the yielding factors in the condensation process. The production rate of condensing water depends principally on relative humidity. Researchers reported that higher air relative humidity will generate a higher amount of water. A controlled and optimal relative humidity procures to original increase in the efficiency of the condensation system. The values of relative humidity stimulate highly feasible changes inefficient performance[22].

2.4. Degree of Subcooling (F_4)

It has been well agreed that subcooling is a temperature of a liquid below its saturation temperature. During the phenomenon of condensation presence of a low degree of subcooling, mobilities drop and transmit to a great extent. As the degree of sub-cooling increases the efficacy performance of condensation rate. The bulk effect of these factors dominants the resistance and predict the accurate rate of condensation and equilibrium[23].

2.5 Dew Point Temperature (F_5)

Water droplets that are formed due to the condensation of moist air on a surface at a temperature less than its dew point temperature are called dew water[24]. The major restriction for huge water volumes is the appropriate dew point temperature. Thus, the dew point is an important factor needed to attain for the completion of the sustainable condensation process.

2.6 Moist Air Rate (F_6)

The presence of moist air initiates the phase transformation from air to water. The rate of moist air will ascribe to the enhanced nucleation of drops and thus the coalescence of droplets accelerates the condensation rate[25]. The harvesting of water from dropwise condensation from moist air depends upon the rate of moist air.

These factors are further assessed based on condensation rate (C_1), efficiency (C_2), time (C_3), and recurring cost (C_4) for calculating weightage criterion.

Fig. 1: Factors influencing the condensation.

3. Methodology, Result and Discussion

3.1 Entropy Weight allocation method

The entropy weight allocation method comes from thermodynamic to information systems and this great work was done by Shannon[26]. Information entropy defined as the incalculability of signals in the communication process and as decrease the information entropy, the weight of criteria is increase[27-29]. The entropy weight allocation method contributes to measuring the relative importance of each criterion which represents the inlaying data provided to the decision maker[23,24].

The entropy weight allocation method has the following advantage as compared to other MCDM processes.

- Comparatively it is easy to study and solve.
- It involves simple mathematical equation-based calculations.
- It also consumes less time.

The weight of specific criterion increases as information entropy decreases, because in the actual world, a value with a low amount of uncertainty is favored when making decisions [28]. The deterministic underpinning for criterion weighting is the idea of entropy. This equipped method is applicable widely and has been used by various researchers like supplier selection[30], order allotment[31], risk evaluation to hydropower station[32], optimization of micro-scale manufacturing processes[33]. Step involved in the entropy weight allocation method is as follows[34-36].

Step 1: Normalizing of a matrix

Available ratios to normalize the data are Weitendorf ratio, Total ratio, Stopp ratio, Schärlig ratio, Körth ratio, Jüttler ratio etc. For this calculation we use total ratio. Equation for total ratio is:

$$\mathrm{Xij} = \frac{\mathrm{Xij}}{\sum_{i=1}^{m} \mathrm{Xij}} \quad (j=1, 2, 3\ldots n) \qquad (1)$$

The assigned value or rating to factors in Table 1 is given on Likert scale rating of 1-5 scale after the brainstorming and discussion with experts of industry, academics, and researchers from research institutes. Normalized data of Table 1 is normalized by using equation 1 and shown in Table 2.

Table 1: Assigned value to factors

Values assigned to factors				
Factors/ Criteria	C_1	C_2	C_3	C_4
F_1	5	4	4	3
F_2	5	3	4	3
F_3	5	4	2	2
F_4	4	2	1	4
F_5	4	3	1	1
F_6	5	4	2	3
Likert scale rating on 1-5 scale				

Step 2: Calculation of Nj value for each criteria

Equation for Nj value is

$$N_j = -k \sum_{i=1}^{n} X_{ij} * \ln(X_{ij}) \quad j = 1,2 \ldots\ldots m \qquad (2)$$

where k = 1/ ln (n)

Calculated Nj value using equation 2 is shown in Table 2.

Step 3: Calculation of Weight for each criteria

Equation for calculating weight for 'j' criteria is.

$$w_j = \frac{1-N_j}{\sum_{j=1}^{n}(1-N_j)} \, where \;\; j = 1, \ldots, n. \qquad (3)$$

Calculated weight using equation 3 is shown in Table 2

Table 2: Criteria weight calculation

	Normalized Factors			
	C_1	C_2	C_3	C_4
	0.1786	0.2000	0.2857	0.1875
	0.1786	0.1500	0.2857	0.1875
	0.1786	0.2000	0.1429	0.1250
	0.1429	0.1000	0.0714	0.2500
	0.1429	0.1500	0.0714	0.0625
	0.1786	0.2000	0.1429	0.1875
N_j	0.9971	0.9851	0.9202	0.9607
$1- N_j$	0.0029	0.0149	0.0798	0.0393
W_j	*0.0214*	*0.1089*	*0.5828*	*0.2869*

With the help of ENTROPY approach, we calculated the weightage of each criteria as mentioned in Table 2.

3.2 Ranking of factors using MOORA Approach

MOORA is an acronym that stands for multi-objective optimization based on ratio analysis [37]. Multi-attribute or multi-criteria optimization is another name for it. This approach optimizes several goals that are in conflict at the same time

In this step, we calculate the ranking of condensation factors considering its criteria weightage calculated in step 3.1 by using the MOORA approach. The steps required to rank the condensation factors using the MOORA method as follows[38,39]

Step 1: Value assigned and Normalization of Factors: The first step in the ranking of condensation factors is to assign the preferred value and further normalized the factors. The value assigned of condensation factors is already done during the weight calculation of criteria by applying entropy weight allocation method as tabulated in Table 2 and normalization of factors using equation 4 is shown in Table 3.

$$X_{ij} = \frac{Xij}{\sum_{j=1}^{n} Xij} \quad (i=1, 2, 3....n) \qquad (4)$$

Step 2: Normalized Assessment of Factors (Yi) However, the case of multiple targets contributes about normalized value added up for all advantageous targets (maximization case) and deducted for all non-advantageous targets (minimization case). Then the final deduced equation for Yi is

$$Yi = \sum_{j=1}^{g} Xij \ - \sum_{j=g+1}^{n} Xij \qquad (5)$$

where the number of advantageous targets is considered to g and (n-g) is the number of non-advantageous targets and Yi is evaluated as the normalized assessment value for ith factors. It Is frequently observed in some cases, that some targets comparatively are found more important than the other existing targets. Subsequently to provide significant importance to a target further across multiplication by its correlated corresponding weight (significant coefficient) is performed[40]. The compiling of these target weights after consideration deduced a new equation is for Yi is

$$Y_i = \sum_{j=1}^{g} Wj * Xij \ - \sum_{j=g+1}^{n} Wj * Xij \ (j=1,2,3.... \ n) \qquad (6)$$

where, Wj resembles the weight of jth goal.
The situation obtained to this work developed criteria weight which is calculated in the previous step; thus, these advantageous and non-advantageous factors are multiplied by corresponding criteria. The assessment of normalization is performed by using equation 6 and thereby the complete calculation is tabulated in Table 3 as shown below.

Table 3: Ranking of Factors

Normalized Factors						
F/C	C_1	C_2	C_3	C_4	Y_i Value	Rank
F_1	0.178	0.200	0.285	0.187	-0.19472486	5
F_2	0.178	0.150	0.285	0.187	-0.20016964	6
F_3	0.178	0.200	0.142	0.125	-0.09353223	2
F_4	0.142	0.100	0.071	0.250	-0.09942064	3
F_5	0.142	0.150	0.071	0.062	-0.04017707	1
F_6	0.178	0.200	0.142	0.187	-0.11146516	4

Step 3: Ranking of condensation factors
The calculated Y_i value can be calculated as positive or negative depending on the totals of its beneficial and non-beneficial targets in Table 3. Thus, it is found that the best factors acquire the greatest Y_i value, while the other factor obtains the least Y_i value. Factors 3 and 5 got the least negative Y_i value which signifies these are solely advantageous factors and all the other factors got the more negative Y_i value which means F_1, F_2, F_4, and F_6 require additional extra input for obtaining some output. As F_5 has -0.0401 and F_3 has -0.0935 Y_i value so, F_5 and F_3 have secured to first and second rank respectively in Table 3.

4. Conclusion

The aim of this research paper is the identification of the most important and high-impact factors which can greatly affect the condensation process of moist air. This research utilized the Entropy weight allocation method to calculate the weightage of criteria such as condensation rate, efficiency, time, and recurring cost. Afterward, the MOORA method is used to provide the ranking of the factors which affect the condensation process.

The result came with two important factors, i.e. dew point temperature (F_5) and relative humidity (F_3). Factor 5 has got the minimum negative value which represents this factor is playing a vital role in the condensation process. Factor 3 came at a second position which means this factor is also carried an important role in the complete process of condensation. Factor 2 (surface coating) and factor 1 (condensing surface) have got the maximum negative value out of six factors, which means that these factors are also important for the condensation process, but they are consuming more inputs in terms of the time and recurring cost and achieve less output as shown in Fig. 2. So, researchers prime focus on the two factors i.e., dew point temperature and humidity, because it will enable the condensation process in an experiment as a comparison to other factors. Table 3 indicates, factors 3 and 5 are consuming fewer inputs in terms of the time and recurring cost and achieve more condensation rate and efficiency as output.

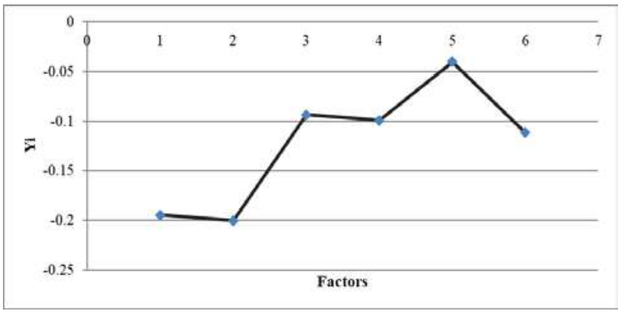

Fig. 2: Graph between Yi and Factors

While condensing atmospheric moist air to a stable dropwise condensation

- Dew point temperature (F_5) has been evaluated with the minimum negative value which represents this factor is playing a vital role in the condensation process. Thus, the condensing surface must attain a temperature lower than dew point temperature to condensate moist air. Thereby, the dew point temperature is marked up as an avenue for phase change.

- Relative humidity (F_3) secures the second position attaining the minimum negative value which means this factor effectively conducts the process of condensation. The dense value of relative humidity specifies ambient temperatures and moisture. Thus, the factor relative humidity needs to be strengthened for an efficient condensation rate.

The ENTROPY and MOORA approach are one of the multi-criteria decisions making (MCDM) methods to evaluate the weightage of the criteria and ranking of the condensation factors. Various other MCDM methods can be applied such as the analytical hierarchical process (AHP), and the VIKOR method for assessment of the factors by taking inputs from different groups of stakeholders from different perspectives. A structural model of factors using total interpretive structural modeling or structural equation modeling techniques will put more light on the impact, relationship, and hierarchy of the factors to understand the moist air condensation process better. The influential hierarchy supports the mechanism of factors augmenting facile, scalable, and economic condensation fetching thermo-physical properties. Therefore, the attained physical and chemical properties by arranging order of factors features to promising stable and sustainable experimental set up. However, the factors asserted required attention to improvise and captivate optimization for contributing to industrial application and scientific modernization.

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Nomenclature

X_{ij}	standardized value of the ith factor in the jth index
N_j	entropy value of the jth index
W_j	weight of the jth criteria
Y_i	normal assessment value for ith factor
g	beneficial criteria number
$n\text{-}g$	non-beneficial criteria number

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